

# Comparing nutrients and volatiles among different tomato varieties

**Guoting Cheng**

Northwest Agriculture and Forestry University

**Peipei Chang**

Shandong Academy of Agricultural Sciences

**Ahmed H. El-Sappah**

Zagazig University

**Yan Zhang**

Northwest Agriculture and Forestry University

**Yan Liang** (✉ [liangyan@nwsuaf.edu.cn](mailto:liangyan@nwsuaf.edu.cn))

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## Research article

**Keywords:** tomato, fruit color, nutrition, volatiles, flavor evaluation

**Posted Date:** May 1st, 2020

**DOI:** <https://doi.org/10.21203/rs.3.rs-23705/v1>

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# Abstract

**Background:** Flavor is an important quality of tomato fruit. The improvement of flavor attracts more and more attention. This study aimed to explore the differences in the concentrations of nutrients and volatiles between red and pink colors of tomatoes fruit, including cherry tomato (*S. lycopersicum* var. *cerasiforme* Mill) and large-fruited tomato (*S. lycopersicum*), respectively.

**Methods:** Soluble sugar, titratable acids, and volatile organic compounds, were detected using gas chromatography-mass spectrometry. Hedonism score and odor activity value were used to evaluate the taste and odor intensity of tomato fruit. The membership function method was used to comprehensively evaluate the fruit flavor.

**Results:** It was found that the levels of aldehydes, ketones, esters, and phenols were significantly higher in pink tomato than in red tomato. The concentrations of ascorbic acid, soluble solids, fructose, glucose, citric acid, and carotenoid-derived volatiles were significantly greater in cherry tomato than in large-fruited tomato. However, Phe-derived and Ile/Leu-derived volatiles were significantly higher in pink large-fruited tomato and red cherry tomato. The fatty and irritant odors were stronger in pink tomato than in red tomato, and cherry tomato had better overall taste than large-fruited tomato. The sweetness and sweetness/acidity ratio were significantly higher in pink cherry tomato than other categories of tomatoes.

**Conclusion:** The concentrations of volatiles varied greatly between pink and red tomatoes, and the levels of nutrients varied greatly between cherry and large-fruited tomatoes. This study can provide reference for tomato flavor quality improvement breeding.

## Background

Tomato is an important vegetable and dual-use fruit product. In 2017, tomato production reached 182.3014 million tons all over the world [1]. Because of its rich nutrition and delicious taste, tomato is widely welcomed by consumers [2]. With the improvement of living standards, not only should people eat enough, but also eat well. However, the flavor and quality of tomato did not be improved with the increase in yield, but decreased in modern cultivated tomatoes [3, 4]. The tomato flavor became less, and the sweetness was lower, causing consumers to complain [5]. The key flavor compounds of tomato included sugar, acid and lots of volatiles [6]. Buttery had identified many volatiles in fresh tomato since the 1980s [7]. Then, many quantitative trait locis (QTLs) of flavor compounds were identified, and their regulatory genes were found [8]. It was found that breeders strived to increase tomato yield and resistance, inadvertently discarded the flavor-related genes, which could control sugar and volatile concentrations [9, 10]. Especially, many key volatiles concentrations declined during tomato evolution. Tieman et al. [9] drew a roadmap for improving tomato flavor quality, hoping to reintegrate the genes controlling tomato flavor into modern cultivated tomatoes through molecular design breeding to improve tomato flavor. Volatiles may affect the flavor at very low concentrations, so they would be a candidate for flavor improvement without sacrificing yield. Our research group has also been working on tomato quality improvement and

breeding of new varieties for more than 30 years. We found pink and red tomato had the highest market share. To investigate the effect of tomato color on flavor, 23 pink and 48 red tomato varieties were used as experimental materials. In this study, nutrients, volatile aromatic compounds, and flavor characteristics were analyzed systematically among pink cherry tomato, pink large-fruited tomato, red cherry tomato, and red large-fruited tomato.

## Results

### Comparison of nutrient concentrations between pink and red tomato fruit

Nutrients were the basis of the flavor and quality of tomato, whose concentrations were shown in Table 1 and Additional file 1. In pink tomato, the soluble solids, fructose and glucose concentrations were more abundant than in red tomato. Pink cherry tomato had more malic acid (0.19%) than red cherry tomato. Citric acid (0.285%) and sugar/acid ratio (4.69) were richer in pink large-fruited tomato than in red large-fruited tomato.

On the other hand, red tomato had more lycopene and ascorbic acid. In cherry tomato, the concentrations of ascorbic acid, soluble solids, fructose, glucose, and citric acid were significantly more than that in large-fruited tomato.

### Comparison of volatiles levels between red and pink tomato fruit

A total of 60 volatiles were detected in this study, including 17 aldehydes, 14 alcohols, 11 ketones, 11 esters, 3 phenols, and 4 other volatiles (Table 2, Additional file 1 and Additional file 2).

The average volatiles components were 41, 39.55, 39.8, and 39.3 in pink cherry, pink large-fruited, red cherry, and red large-fruited tomato, respectively. Total concentrations of volatile were  $2.51 \times 10^{-5}$ ,  $2.20 \times 10^{-5}$ ,  $2.04 \times 10^{-5}$ , and  $1.62 \times 10^{-5}$  kg L<sup>-1</sup> in turn. 1-(2,6,6-Trimethyl-1-cyclohexen-1-yl)-2-buten-1-one was not detected in pink cherry tomato and red large-fruited tomato. 2-Methoxyphenol and 4-heptyl isobutyl phthalate were not detected in red cherry tomato. The levels of aldehydes, alcohols, ketones, esters, phenols, and other volatiles accounted for 30.12%, 28.20%, 18.95%, 16.85%, 2.77%, and 3.21%. C<sub>6</sub> compounds were abundant. Hexenal, (*E*)-2-hexenal, 1-hexanol, (*Z*)-3-hexenol, and (*E*)-2-hexenol accounted for 31.65%. Among the detected volatiles, the following volatiles have bigger odor activity values (OAVs); namely, (*E*)-2-hexenal (46.05), (*E,E*)-2,4-decadienal (44.88), and 6-methyl-5-heptene-2-one (33.93), hexenal (31.95), 2,6,6-trimethyl-1-cyclohexene-1-carboxaldehyde (28.09), 2-isobutylthiazole (23.74), (*E*)-6,10-dimethyl-5,9-undecadien-2-one (19.94), (*E*)-2-octenal (19.23), 4-allyl-2-methoxyphenol (17.25), (*Z*)-3-hexenol (15.96), (*Z*)-2-heptenal (15.72), methyl salicylate (12.24).

Pink tomato had higher levels of total volatiles, aldehydes, ketones, esters, and phenols than red tomato. The lipids and carotenoids derivatives were significantly higher in pink tomato than in red tomato, such as hexenal, (*E*)-2-hexenal, (*E*)-2-octenal, (*E*)-2-nonenal, decanal, (*E*)-2-decenal, (*E,E*)-2,4-decadienal, 2,6,6-trimethyl-1-cyclohexene-1-carboxaldehyde, 3-(4-methyl-3-pentenyl)-furan, 6-methyl-5-hepten-2-one, and 4-

(2,6,6-trimethyl-1-cyclohexen-1-yl)-3-buten-2-one. As the OAVs showing, the green and irritant odors in pink tomato were stronger than those in red tomato. In pink cherry tomato, the concentrations of ketones and aldehydes were significantly higher than other categories tomatoes, especially, 1-octen-3-one, (*E*)-6,10-dimethyl-5,9-undecadien-2-one ( $1.38 \times 10^{-6} \text{ kg L}^{-1}$ ), (*E,Z*)-6,10-dimethyl-3,5,9-undecatrien-2-one, 2,6,6-trimethyl-1-cyclohexene-1-carboxaldehyde ( $2.21 \times 10^{-7} \text{ L}^{-1}$ ), (*2E*)-3-(3-pentyl-2-oxiranyl)acrylaldehyde ( $9.04 \times 10^{-7} \text{ kg L}^{-1}$ ), and 3,7,11-trimethyl-2,6,10-dodecanetrienal ( $1.74 \times 10^{-7} \text{ kg L}^{-1}$ ) were the highest. These volatiles mainly derived from fatty acids and carotenoids. The OAVs of volatiles with fatty odor were significantly more in pink cherry tomato. On the other hand, in pink large-fruited tomato, phenols ( $9.61 \times 10^{-7} \text{ kg L}^{-1}$ ) and other volatiles ( $8.66 \times 10^{-7} \text{ kg L}^{-1}$ ) levels were the highest, such as 4-allyl-2-methoxyphenol ( $5.43 \times 10^{-7} \text{ kg L}^{-1}$ ) and 2,4-bis(1,1-dimethylethyl)-phenol ( $1.68 \times 10^{-7} \text{ kg L}^{-1}$ ).

In red cherry tomato, alcohols concentrations were the highest, such as 3-methyl-1-butanol ( $3.64 \times 10^{-7} \text{ kg L}^{-1}$ ), 1-pentanol ( $1.45 \times 10^{-7} \text{ kg L}^{-1}$ ), hexanol ( $3.27 \times 10^{-6} \text{ kg L}^{-1}$ ), (*Z*)-3-hexenol ( $1.57 \times 10^{-6} \text{ kg L}^{-1}$ ), (*E*)-2-hexenol ( $3.41 \times 10^{-7} \text{ kg L}^{-1}$ ), (*E*)-2-octenen-1-ol ( $2.48 \times 10^{-7} \text{ kg L}^{-1}$ ). These compounds were mainly derived from lipids metabolism. The sweet odor was significantly stronger in red cherry tomato than in other categories of tomatoes. However, red large-fruited tomato had lower volatiles levels.

### Flavor sensory evaluations of red and pink tomato

The scores of the sensory evaluation are shown in table 3 and Additional file 1. All of the sensory evaluation scores were higher in pink tomato than those in red tomato. Pink cherry tomato had significantly higher sweetness (6.31 points) and sweetness/acidity ratio than other categories of tomatoes. Besides, the sweetness, overall taste, tomato characteristic flavor, sweetness/acidity ratio, and were more 2.09, 1.52, 1.01, and 0.6 points higher in pink cherry tomato than red cherry tomato, respectively. Correspondingly, their scores were higher 0.45, 1.15, 0.5, and 0.12 points in pink large-fruited tomato than in red large-fruited tomato. Whereas the acidity score was more 0.39 point in red cherry tomato than in pink cherry tomato.

Comprehensive flavor evaluation values (*Y*) of various categories tomato are shown in table 3 and additional file 1, obtained using the membership function method. Three principal components were extracted from sensory evaluation scores and odors activity values, which could be explained 72.814% variance. According to the formula (5), the following formula could be used to calculate comprehensive flavor evaluation value of each tomato variety.

$$Y = (\alpha_1 \times F_1 + \alpha_2 \times F_2 + \alpha_3 \times F_3) / (\alpha_1 + \alpha_2 + \alpha_3) = (32.742 \% F_1 + 23.692\% F_2 + 16.38\% F_3) / 72.814\%$$

The values of comprehensive flavor evaluation were 0.49 (pink cherry tomato), 0.24 (red cherry tomato), 0.15 (pink large-fruited tomato), and -0.24 (red large-fruited tomato), respectively. Comprehensive flavor evaluation values can show that pink tomato have better flavor than red tomato, and cherry tomato are more delicious than large-fruited tomato.

## Correlation analyses of key flavor factors in tomato fruit

In order to further explore the contribution of nutrients and volatiles to tomato flavor, the Pearson correlations were studied between compound concentration and flavor intensity. For the sake of brevity, only the items are shown in Table 4 and Additional file 1 with a significant correlation or very significant correlation.

The concentrations of ascorbic acid, soluble solids, fructose, glucose, citric acid had a significantly positive correlation with the evaluation score of sweetness, sweetness/acidity ratio, tomato characteristic flavor, overall taste, comprehensive flavor evaluation. The sugar/acid ratio was a very significant positive correlation with the overall taste (0.307\*\*). Many volatiles had a significantly positive correlation with comprehensive flavor evaluation, fatty, green, floral and fruity, vegetable-like, and irritant odors. According to metabolic precursors, the carotenoid-derived volatiles had a significantly positive correlation with the floral and fruity odor. There was a significantly positive correlation between the lipid-derived volatiles and green, floral and fruity odors. The branched amino acid derivatives were significantly positively correlated with the green and vegetable odors. The Phe-derived volatiles were significantly positively correlated with the irritant odor. In addition, the overall taste was significantly positively correlated with 4-allyl-2-methoxyphenol (0.393\*), (*E,E*)-2,4-decadienal (0.302\*). The tomato characteristic flavor had significantly positively correlated with 3,7-dimethyl-6-octen-1-ol (0.726\*), (*E,E*)-2,4-decadienal (0.247\*). Sweetness/acidity ratio had a significantly positive correlation with 2-phenylethanol (0.894\*\*), (*Z*)-3-hexenol (0.310\*\*), isopropyl palmitate (0.602\*), (*E*)-2-hexenol (0.493\*), 1-octen-3-one (0.427\*), 2,4-decadien-1-ol (0.349\*), methyl hexadecanoate (0.298\*), 1-pentanol (0.251\*), and 2-phenylethanol (0.235\*). Sweetness was significantly positive correlated with (*E,E*)-2,4-decadienal (0.350\*\*), 6-methyl-5-hepten-2-ol (0.388\*), (*2E*)-3-(3-Pentyl-2-oxiranyl)acrylaldehyde (0.310\*), methyl hexadecanoate (0.279\*), (*Z*)-3-hexenol (0.260\*), and 1-pentanol (0.245\*). Acidity had a significantly positive correlation with 2-methoxyphenol (0.901\*).

## Discussion

Fruit color is an important commodity character [16], which will affect consumers' purchasing desire. Pink and red are the most common tomato fruit colors. Pink tomato is caused by a mutation in the *SIMYB12* of red tomato, resulting in a lack of yellow-colored flavonoid naringenin chalcone in the peel [17]. Pink tomato took a large market proportion in Asia due to their fruit with bright color, uniform size, fine flesh, and strong flavor [8]. Lycopene,  $\beta$ -carotene concentrations and taste index were higher in pink tomato than those in red tomato [18]. Carotenoids had diverse bioactive and chemical properties [19]. Pink tomato had higher nutrition and health care effect. This study found that pink tomato had higher soluble solids, fructose, glucose, aldehydes and ketones than red tomato, which made pink tomato have higher sweetness, tomato characteristic flavor, and overall taste. Although the gender and age factors of the panels were fully taken into account, these panels are mainly from China, preference for pink tomato. Therefore, the results of flavor evaluation had some limitations. Soluble sugar and organic acids could provide the basic flavor for fruit and vegetables, while the characteristic aromas of volatiles were the

main indicator to distinguish the flavor among different fruit and vegetables [20–23]. Hundreds of volatiles were found in tomato, but only dozens of them play a role in flavor [24, 25]. These key aroma volatiles had lower threshold concentrations in water. For example, although the carotenoid derived volatiles had very low levels, they contributed a lot to the flavor. In this study, the carotenoid derivatives were higher in pink tomato than that in red tomato; namely, 2,6,6-trimethyl-1-cyclohexene-1-carboxaldehyde, (*Z*)-3,7-dimethyl-2,6-octadienal, 6-methyl-5-hepten-2-one, and 4-(2,6,6-trimethyl-1-cyclohexen-1-yl)-3-buten-2-one. These isoprene volatiles had strong floral and fruity odor. Some of them could increase the sweetness of tomatoes [9, 26, 27]. Less sweetness was what made tomatoes taste worse [28]. The sensory evaluation was a positively correlation with the tomato wholesale price [29]. Pink tomato also had higher fatty acid derivatives, such as hexanal, (*E*)-2-hexenal, (*Z*)-2-heptenal, nonanal, (*E,E*)-2,4-decadienal, 1-octen-3-one. These volatiles with grassy odor could increase the freshness of tomato. Notably, (*E,E*)-2,4-decadienal had significantly positively correlated with sweetness, tomato characteristic flavor, and overall taste. Zhu et al. [2] found that hexanal and  $\beta$ -ionone had positively correlated with sweetness and tomato flavor intensity. (*E*)-2-hexenal, (*E*)-2-heptenal, (*Z*)-3-hexenol, 2-phenylethanol, 6-methyl-5-hepten-2-ol, 6-methyl-5-hepten-2-one, 1-penten-3-one, and 2-isobutylthiazole were positively related to consumer liking [30–33]. It may enhance pink tomato flavor by small increasing the concentrations of fatty acid and carotenoid derivatives without sacrificing yield or fruit size. Luckily, Yang et al. was able to generate pink-fruited tomato plants using CRISPR/Cas9-mediated targeted mutagenesis of SIMYB12 [34].

In contrast, consumers prefer red tomato in European and American [8]. This study found that red tomato had more lycopene, and ascorbic acid with higher acidity. The concentrations of the Phe-derived and Ile/Leu-derived volatiles, alcohols, (*E*)-6,10-dimethyl-5,9-undecadien-2-one, 1-(2,6,6-trimethyl-1-cyclohexen-1-yl)-2-buten-1-one, and methyl salicylate were higher in red cherry tomato than in pink cherry tomato.

Fruit size is one of traits affecting consumer preferences. Both the smaller and bigger size tomatoes are tastier comparing with medium size tomatoes [18]. Cherry tomato is popular among consumers with high sweetness and fine fruit type. In this study, cherry tomato had a significantly higher nutrients and volatiles; namely, ascorbic acid, soluble solids, fructose, glucose, citric acid, alcohols, aldehydes, ketones, and esters. More concentrations of flavor compounds make the flavor better. Comprehensive flavor evaluation of cherry tomato was significantly higher than large-fruited tomato. Because cherry tomato had small fruit size, which made higher concentrations of photosynthetic products, sweetness, etc. As table fruit, cherry tomato is more and more popular with consumers. Previous study said that cherry tomato had higher fructose, glucose, soluble solids, total polyphenols, carotenoids, sweetness, and acidity than fresh market tomatoes, which were good for consumers' health [35, 36].

Since the same category of tomatoes were compared with other categories of tomatoes as a whole, some tomato varieties were not reflected with special flavor characteristics, e.g. the rankings of comprehensive flavor evaluation of two red cherry tomato, CI1009 and CI1005 varieties, were the second and third among 76 tomatoes varieties. To our surprise, one red large-fruit tomato, TI1022 variety, ranked the sixth in flavor.

# Conclusions

The flavor was better in pink tomato than in red tomato, while the flavor was better in cherry tomato than in large-fruited tomato. Pink tomato had higher volatiles levels with better odor than red tomato. Cherry tomato had more nutrient contents with better taste than large-fruited tomato.

There was a strong correlation between nutrients concentrations and sensory evaluation scores, the same to volatiles levels and odors intensity. However, there was lower correlation, between volatiles levels and sensory evaluation scores or between nutrients contents and odors intensity.

# Methods

## Tomato varieties

The tomato varieties for the experiment were shown in Additional file 3, including 8 pink cherry tomato varieties (PC1 – PC8), 15 pink large-fruited tomato varieties (PL1 – PL15), 11 red cherry tomato varieties (RC1 – RC11), 37 red large-fruited tomato varieties (RL1 – RL8), which were provided by the Tomato Genetic Breeding and Quality Improvement Team of Northwest A & F University. Seedling cultivation was carried out in a greenhouse from January 2019. Tomato seedlings were planted in a plastic greenhouse in Yangling City of Shaanxi Province in March, 2019. The third ear tomatoes were selected at the pink ripe stage [37]. Then, nutrients and volatiles were measured, and various flavor intensities were evaluated. Tomato samples required consistent size, uniform coloring, and no deformities, cleft fruit and rot. The determination of each flavor factor has three biological replicates.

## Experiment methods

a. Lycopene was determined by high performance liquid chromatography (HPLC) [38].

b. Ascorbic acid (AsA) was measured by molybdenum blue colorimetry. The absorbance is measured at OD<sub>760nm</sub>. After comparing with the standard curve formula (1), the AsA concentration is calculated according to the formula (2):

$$\text{AsA standard curve: } c = 1543.424A - 1.995, \quad R^2 = 0.991 \quad (1)$$

AsA concentration calculation formula:

$$\text{AsA (\% FW)} = c \times V / (W \times a) \times 100 \quad (2)$$

Where A is the absorbance at OD<sub>760 nm</sub>. c is the AsA concentration (kg L<sup>-1</sup>) in the sample obtained from the standard curve, V is Total volume of the sample extract (L), W is the mass of tomato fresh tissue (kg), and a is the volume of the sample extract (L) used in the measurement.

c. The soluble solids were measured by dripping tomato juice directly on a PAL<sup>-1</sup> digital refractometer (Japan Atago Co., Ltd.).

d. Soluble sugar and titratable acids were determined using gas chromatography-mass spectrometry (GC / MS) method. The methoxyamine was used to derivatize treatment [39, 40].

e. Qualitative and quantitative analysis of volatile aromatic compounds was taken by headspace solid-phase microextraction (HS-SPME) gas chromatography-mass spectrometry (GC/MS) method [41–43]. The samples were crushed with a homogenizer (Specimen model factory in Shanghai, China). 0.05 kg sample, 10<sup>-5</sup> L of 3.284 × 10<sup>-5</sup> kg L<sup>-1</sup> 3-nonanone (as internal standard), 0.05 kg of anhydrous NaCl and a magnetic rotor were added to the headspace bottle. The aromatic volatile compounds were extracted with 7.5 × 10<sup>-5</sup> m CRA/PDMS extraction head (Supelco, USA) for 2400 s at 50°C. GC/MS of ISQ (Thermo Scientific, USA) has a polar elastic quartz capillary chromatographic column (UP-INNOWAX). The volatiles were dissociated for 150 s at 40 °C. The column temperature rose to 110 °C at a rate of 0.17 °C s<sup>-1</sup>, increased to 230 °C at a rate of 0.10 °C s<sup>-1</sup>, and kept for 600 s. Three biological replicates were performed for each sample.

RT of each normal alkane was measured under the same GC/MS conditions after mixing the C<sub>4</sub> – C<sub>26</sub> normal alkanes standard solution. Then, RI was calculated of each volatile compound according to the following formula:

$$RI = 100Z + 100 [\log t'R(x) - \log t'R(z)] / [\log t'R(z+1) - \log t'R(z)] \quad (3)$$

t'R is the retention time, and Z and Z + 1 are the number of carbon atoms in the normal paraffin before and after the target volatiles (X) flow out, respectively. t'R(z) < t'R(x) < t'R(z + 1).

Qualitative analysis of volatiles was compared with the standard mass spectrum of the library (NIST2011, USA) and RI [44]. Only the volatiles were selected, whose both positive and negative matches were greater than 800 with mass spectrometry. The peak area normalization method was used to calculate the relative concentration of various volatiles. Due to errors were inevitable in GC/MS measurement values. The measured volatiles concentrations must be corrected according to the calibration curve. In this study, 0, 5 × 10<sup>-6</sup>, 10<sup>-5</sup>, 1.5 × 10<sup>-5</sup>, 2 × 10<sup>-5</sup>, 2.5 × 10<sup>-5</sup>, or 3 × 10<sup>-5</sup> L 3-nonanone standard solutions (3.284 × 10<sup>-5</sup> kg L<sup>-1</sup>) was added respectively to 0.005 kg different tomato samples. 3-Nonanone concentration was measured under the same GC/MS conditions in different samples. Linear regression was performed between the concentration measured by GC/MS and the theoretically calculated concentration. The calibration curve was as follows:

$$y = 1.004x - 0.044, R^2 = 0.998 \quad (4)$$

According to the calibration curve (4), the concentration of each volatile was determined.

f. Sensory evaluation methods of sweetness, acidity, characteristic flavor and overall taste referenced literature [2, 38, 44–47], slightly changed. Different tomato samples were numbered and cut to form wedge shapes. The panels of trained and tasting wore eye patches to evaluate tomato flavors. The panels are made up of 25 males and 25 females, whose ages are between 18 and 60 years old. In advance, we tentatively had a maximum score of 8.00 points. They scored the sweetness, acidity, tomato characteristic flavor and overall taste according to the flavor intensity and sensory pleasure. The stronger the flavor, the higher the score. The better the sensory pleasure, the higher the score. After tasting a sample, the panels should rinse the mouth with purified water three times. To reduce taste and smell fatigue, tasted for 2700 s and rested for 900 s.

## Data statistics

All test data was recorded by WPS Office 2019. The tomato varieties were divided into four categories for pink cherry tomato, pink large-fruited tomato, red cherry tomato, and red large-fruited tomato varieties. Data for each measure were averaged in the same category of tomato varieties. The intra-group SD and the variation coefficient of the same category tomato varieties were calculated. Then, the date differences were analyzed among the four categories by one-way analysis of variance ( $P < 0.05$ ) using SPSS 17.0. Z-Score standardized the data of tomato nutrients and volatiles levels and sensory evaluation scores. Pearson correlation analysis was performed among different flavor factors. Then, the membership function method was used to evaluate the flavor of each tomato variety comprehensively. The principal component analysis was performed (suppose two principal components were extracted). Comprehensive flavor evaluation value ( $Y$ ) of each tomato variety calculated according to the following formula:

$$Y = (\alpha_1 \times F_1 + \alpha_2 \times F_2) / (\alpha_1 + \alpha_2) \quad (5)$$

$\alpha_1$  means the variance contribution rate of principal component 1 (PC1).  $F_1$  is the factor score of PC1.  $\alpha_2$  likes  $\alpha_1$ , and  $F_2$  likes  $F_1$ , and so forth.

The bigger the  $Y$  value, the more delicious the tomato variety. Two-variable Pearson correlation analysis was performed among nutrients concentrations, volatiles levels, OAVs of volatiles, sensory evaluation scores using SPSS 17.0.

## Abbreviations

PC: pink cherry tomato; PL: large-fruited tomato; RC: red cherry tomato; RL: red large-fruited tomato; QTL: quantitative trait loci; SD: standard deviation; RT: retention time; RI: retention index; OAV: odor activity values; HPLC: high performance liquid chromatography; AsA: ascorbic acid; HS-SPME: headspace solid-phase microextraction; GC/MS: gas chromatography-mass spectrometry; PC: principal component; FAO: Food and Agriculture Organization of the United Nations.

## Declarations

## **Ethics approval and consent to participate**

Not applicable.

## **Consent for publication**

Not applicable.

## **Availability of data and materials**

All data generated or analyzed during this study are included in this published article and its supplementary information files.

## **Competing interests**

The authors declare that they have no competing interests.

## **Funding**

This work was supported by The National Key Research and Development Program of China (2016YFD0101703) and New Varieties of Solanaceous Vegetables (2019ZDLNY03-05).

The funder (Pro. Yan Liang) contributed to conceptualization, resources, writing—review and editing, supervision, project administration, and funding acquisition in this study. The funder had no subjective effect on the results.

## **Authors' Contributions**

conceptualization, **Y.L.** (Yan Liang) and **G.C.** (Guo ting Cheng); methodology, **P.C.** (Peipei Chang) and **G.C.**; software, **G.C.** and **P.C.**; validation, **G.C.**; formal analysis, **G.C.**; investigation, **G.C.** and **P.C.**; resources, **Y.L.**; data curation, **G.C.**; writing—original draft preparation, **G.C.**; writing—review and editing, **Y.L.** (Yan Liang), **Y.Z.** (Yan Zhang) and **A.E.** (Ahmed.H.El-Sappah); visualization, **G.C.** and **A.E.**; supervision, **Y.L.**; project administration, **Y.L.**; funding acquisition, **Y.L.**. All authors have read and agreed to the published version of the manuscript.

## **Acknowledgements**

Thank for the tomato material provided by the Tomato Genetic Breeding and Quality Improvement Team of Northwest A & F University. Thanks also to Jing Zhang and Jing Zhao for assistance in the use of GC-MS instruments in this experiment. Thanks also to Dr. Tayeb Muhammad for correcting the English in this paper.

## **Author details**

<sup>1</sup> College of Horticulture, Northwest A&F University, Yangling 712100, Shaanxi P. R., China. <sup>2</sup> State Key Laboratory of Crop Stress Biology in Arid Regions, Northwest A&F University, Yangling 712100, China. <sup>3</sup> Institute of Agricultural Science, Dezhou 253015, Shandong P. R., China; <sup>4</sup> Genetics Department, Faculty of Agriculture, Zagazig University, 44511 Zagazig, Egypt.

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## Tables

Due to technical limitations the tables are available in the Supplementary Files as downloads.

## Supplementary Information

**Additional file 1.xls: Table S1.** The concentrations of nutrients (%) and volatiles ( $10^{-9}$  kg L<sup>-1</sup>) in each tomato accession and their sensory evaluation.

**Additional file 2.xls: Table S2.** Concentrations and OAVs of different types volatiles in pink and red tomato fruit.

**Additional file 3.xls: Table S3.** Tomato varieties for experimentation and their comprehensive flavor evaluation.

## Supplementary Files

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